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INFLUENCING OF MAXIMUM EXPLOSIVE PARAMETERS OF IGNITION ENERGIES OF DUST-AIR MIXTURES

Vojtech JANKUJ[1], Ales BERNATIK[2]

Research article

Abstract: This article deals with maximum explosive parameters of dust-air mixtures and their influencing of ignition energies. Pyrotechnic ignitors were mixed and assembled in this experimental measurements. These assembled pyrotechnic ignitors were recorded with high-speed camera. Obtained records were used for describing their behaviour after activation. Pyrotechnic ignitors were modified and then were used for ignition of selected dust-air mixtures in the final stage of this experimental measurements. This test was carried out using an explosion autoclave where the optimal concentration of selected dust-air mixtures was used.

Keywords: Initiation energy; explosion; dust explosion; optimal concentration; maximum explosive parameters.

Introduction

A fire is a process when three conditions are present. These conditions include a flammable substance (fuel), an oxygen (air oxygen) and sufficient ignition energy (flame, heat). These three conditions together are called “fire triangle” (See Fig. 1). If all three conditions are present simultaneously, the fire is observed. During this process, the energy and the light are released. (Damec, 1999; Damec, 2005)

Fig. 1. Fire triangle (Combustible Dust Safety Q&A, 2014)

In the case of dust-air mixtures, there exists two other conditions. The explosion occurs if the mixture is dispersed and mixed with oxygens within the explosive limits. As a fifth and last condition is taken a confinement effect. These two conditions complete the fire triangle on “explosive pentagon” (See Fig. 2). Also, the high amount of heat and gases are released during the explosion. (Damec, 1999; Damec, 2005)

Fig. 2. Explosion pentagon (Combustible Dust Safety Q&A, 2014)

The greatest consequences of the explosion appear if the optimal concentration of the dust with

1 VŠB-Technical university of Ostrava, Faculty of safety engineering, Ostrava, Czech Republic, vojtech.jankuj@vsb.cz

2 VŠB-Technical university of Ostrava, Faculty of safety engineering, Ostrava, Czech Republic, ales.bernatik@vsb.cz

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oxygen is reached. This concentration is manifested by maximal explosion pressure and maximal rate of pressure (Damec, 2005). In the Czech Republic, the standard ČSN EN 14 034 (2011) was developed for this problem. This standard defines experimental methods for determination of these parameters. These parameters are also used as a base for explosion prevention. For the determination of explosive parameters are used explosion autoclaves which are pressure devices of a defined volume. In this volume, defined amount of dust is dispersed and subsequently ignited. The explosion autoclaves contain sensors which monitor times and pressure, and the control computer which evaluates these values to determine the explosive parameters. (ČSN EN 14 034, 2011; Siwek, 2016)

The standard specifies also the manner of initiation of the prepared weights. Standardly, the igniters developed by Dortmund Sobbe Company are use. The Sobbe Company supllies on the market the igniters of different energies (from 100 J to 10,000 J). For the dust mixtures, the initiation energy of 10 kJ is established by the standard to which two initiators with the corresponding energy of 5 kJ (See Fig. 3) developed by Sobbe Company are used. (Technical data sheet Ebbos ChZ., 2016)

Fig. 3. Sobbe ignitors of 5 kJ energy

In the addition to the measurement procedures and the determination of the minimal initiation energy, also the exact composition was stated in the standard before the amendment in 2011:

- zirconium (40%) - 0.48 g,
- barium nitrate (30%) - 0.36 g,
- barium peroxide (30%) - 0.36 g.

This way prepared the initiation source should have weight 1.2 g and its energy should correspond to an energy 5 kJ (Jankuj, 2017). A further condition is that this pyrotechnic initiator has to be able to ignite the mixture within 10 ms and has to produce light and sparks. On these data was based the experimental preparation of alternative initiation sources. (ČSN EN 14 034, 2011)

Materials and methods

The experimental part was devoted to the possibility and preparation of alternative initiation sources, their comparison and verification of functionality using the Sobbe igniter. Instead of zirconium, the metal aluminium and magnesium in the dust form were selected as the replacement in the pyrotechnical mixture.

To build a dust pyrotechnical mixture, it was necessary to determine the combustion heat of aluminium and magnesium to match the energy 5 kJ. Values of the combustion heats were taken from the book Ignition Handbook. This book is mainly focused on the problems of initiation. For aluminium, the value 31,060 $J.g^{-1}$ and for magnesium 24,730 $J.g^{-1}$ were given in this book. On the basis of these combustion heats were calculated and build the individual pyrotechnical mixtures. (Babrauskas, 2003)

If an electric moment igniter, which is used for initiation of pyrotechnical mixture, gives the energy 86 J, out of dust mixtures have to be obtained energy of size 4,914 J. To this energy corresponds the weight 0.16 g of aluminium and 0.2 g of magnesium. Then were for given mixtures calculated weights of barium peroxide and barium hydroxide. The total weight of the dust mixture was 0.4 g for aluminium and 0.5 g for magnesium. For comparison with the Sobbe igniter with 1 kJ energy, nitrocellulose was also prepared where 1 kJ energy corresponds the weight 1 g (Jankuj, 2017). The mixed pyrotechnical mixtures were plugged in the used cups of Sobbe igniters, in which the electric moment igniter was placed and fasten. The plugging of mixture in the cup was performed using several types of caps.

A workplace was created in the laboratory where controlled initiation of these prepared pyrotechnical mixtures was performed. All measurements were monitored using high speed camera. This camera enables to see the whole initiation in detail resolution, to find out the difference of particular mixtures and at the same time it is possible to evaluate the time requirement of the initiation start within10 ms. The workplace itself was composed of several items. One of the most important was high-speed camera Photron FASTCAM SA-Z and the laboratory source with synchronization unit. These three instruments were interconnected and because of the synchronization unit was running both the source and the camera at the same time. The background consisted of black canvas with a target, in the centre of which the igniters were placed on the laboratory stand with the supplied source (See Fig. 4). The camera scanned at a rate of 5,000 frames per second and the igniter was illuminated by five spotlights. The records were saved in the highest quality and subsequently visually compared.

Fig. 4. Prepared workplace

Another instrument used for the final evaluation was the explosive autoclave 20-L Apparatus (See Fig. 5) manufactured by Kühner AG Company located in Basel. This instrument consists of a test chamber which has the volume 20 l and is created by double shells into which water is pumped for cooling purposes. Several inputs are situated in the chamber, in which measuring sensors are located. In addition to the evaluation of the dust explosion parameters is this instrument also able to measure the parameters of combustible gases and hybrid mixtures. This chamber is then connected to the control unit as well as to the measure and control devices. The individual elements are interconnected and the signal is sent to the computer where is created the user interface using the software. (Siwek, 2016)

The device is able to determine maximal explosion parameters of dusts and gases, cubic constant, lower explosion limit, and also limiting oxygen concentration value. It is also able to evaluate explosivity for dust mixtures. When the hybrid mixtures are evaluated, it can measure maximal explosion parameters and determine the cubic constant. (Siwek, 2016)

Fig. 5. Explosion autoclave 20-L Apparatus

In order to assess the influence of maximal explosion parameters using the initiating energy the following substances in the dust form were selected:

- Niacin;
- Lycopodium;
- Blue toner colour;
- Black coal.

Niacin

Niacin is the acronym for **NI**cotin **AC**id vatam**IN** denoting nicotinic acid, which is an organic white solid (See Fig. 6). In the form of dust, the niacin can form the explosive concentrations with oxygen and at the same time can irritate the respiratory tract after inhalation. The optimal concentration corresponds to 500 g.m^{-3}. (Technical data sheet Niacin (Nicotin Acid), 2012)

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Fig. 6 Niacin powder

Lycopodium

Another of the used dusts was Lycopodium. This are dry spores of Lycopodia clavatum (See Fig. 7). Also, in this case it can create the explosive concentration in the presence of oxygen and a sufficiently strong initiation source. It produces large and impressive flashes of flames, and therefore it can be used in fireworks or in special effects. Optimal concentration is, as in the previous case, 500 g.m^{-3}. (Lycopodium clavatum, 2015)

Fig. 7. Lycopodium powder

Blue toner colour

Toner dust is an integral part of toner cartridges of laser printers. A very fine powder of blue toner colour was used (See Fig. 8). Again, the optimal concentration corresponds to 500 g.m^{-3}. (Li et al., 2012)

Fig. 8. Blue toner colour powder

Black coal

The last tested dust sample was black coal (See Fig. 9), a type of sedimentary rock from organic material. This material is mainly used for heat energy gain. Optimal concentration of black coal is less than half of the previous three types of dust, concretely 250 g.m^{-3}. (Black coal: Kulda Ecofuel, 2018).

Fig. 9. Black coal powder

Results

This chapter deals with description of behaviour of each initiating sources after their activation. It is about mutual comparison of their visual exposures. Concretely, the exposure of pyrotechnical igniter created by Sobbe Company and two laboratory prepared igniters with aluminium and magnesium as the main energetic item were compared.

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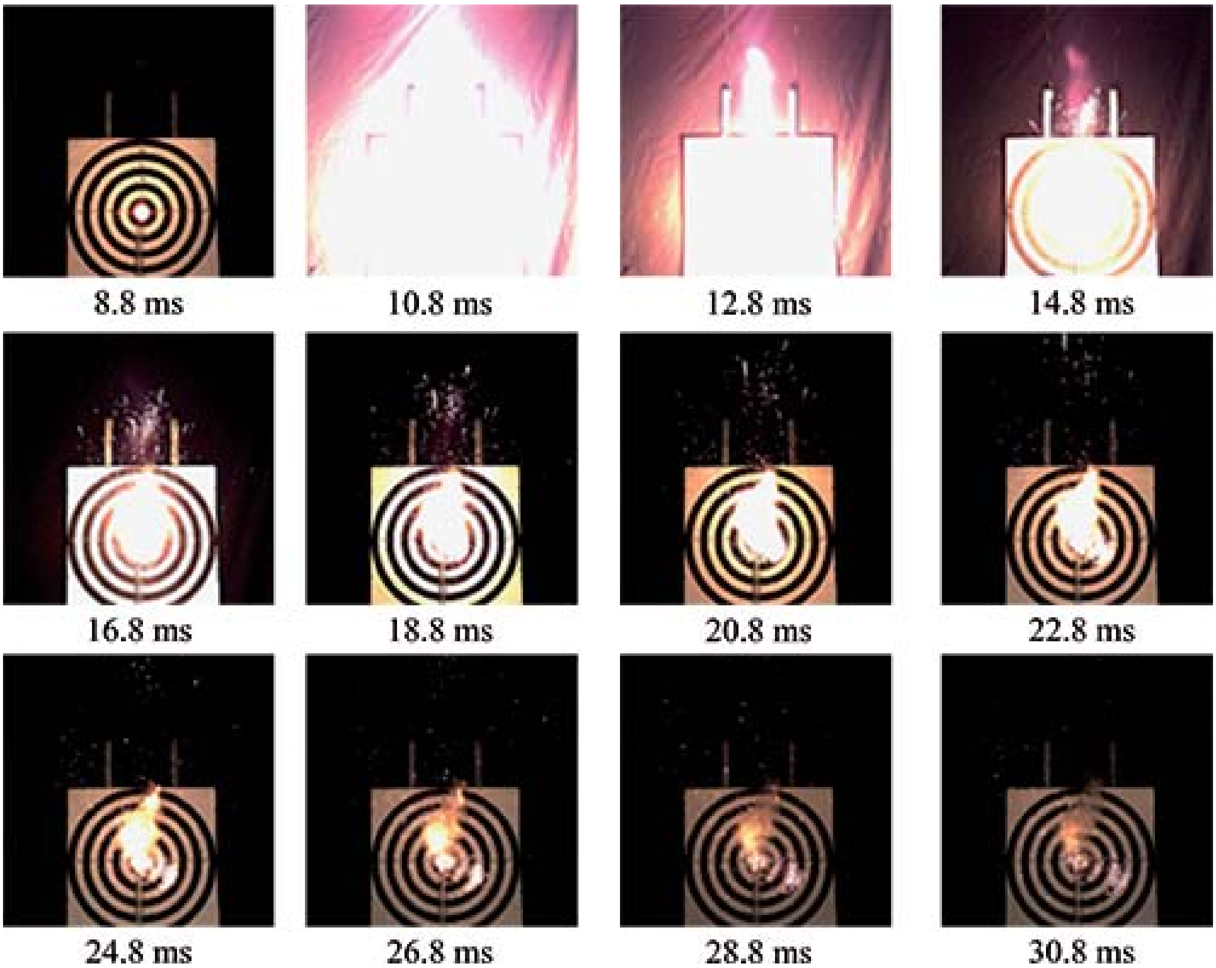

Fig. 10. Initiation of Sobbe igniter

Sobbe Igniter

The igniter of Germany Sobbe Company was the first monitored igniter. Igniters with both 5 kJ and 1 kJ initiation energy were monitored. The sole initiation of these igniters was very fast, the intense light exposure appeared and when the cap was released accompanied by a sound effect. For both types, the first exposure took place within 10 ms, only in one case the limit set by the standard was exceeded. The following sequence of images represent the progress of the initiation. The first visible exposure (See Fig. 10) a sign of the sole initiation can be seen on the first image in the sequence (8.8 ms) followed by the own progress of the initiation. There can be seen the already mentioned intense light exposure, which slowly fades.

Aluminium and Magnesium

Two types of aluminium with different grain size, coarse with grains of 52 μm in size and finer with grains of 26 μm in size, were used to prepare the pyrotechnical mixtures with aluminium. For the magnesium, the grain size 200 μm was determined. During the first measurements, the problem in sealing of the mixture inside the cup was discovered. The original three designed seal caps were unable to hold the mixture inside the cup for a sufficient amount of time. This resulted in unwanted release of the unignited mixture out of the cap which was ignited in the space. This effect caused a slowing of the initiation and the required limit 10 ms was exceeded. The greater reaction of the finer aluminum was expected however due to its softness, the mixture burnt twice, in the space and in the cup.

The following sequence of images (See Fig. 11) shows the progress of the initiation of the dust mixture of the aluminium with finer grains. The first sign of the exposure of this mixture is releasing of unignited mixture on the first snapshot followed by the initiation on the second snapshot. Then, the sole initiation follows ending approximately

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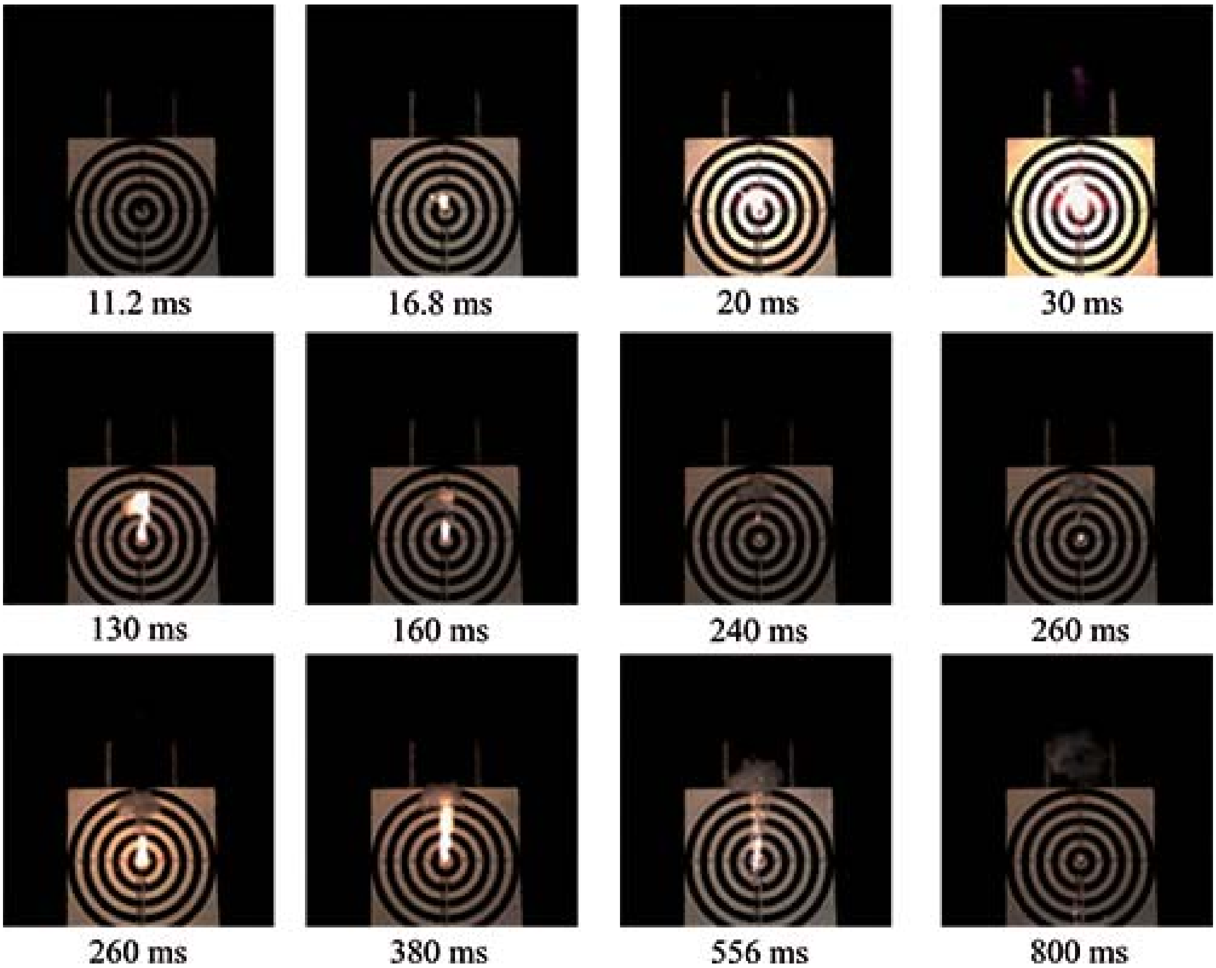

Fig. 11. Initiation of Aluminium igniter

in 240 ms. After that, also the pyrotechnical mixture remaining in the cup is ignited. This initiation was an undesirable effect causing that whole initiation was longer then the initiation of Sobbe igniters.

However, from the records, it was possible to trace the improvement of the initiation exposure and its acceleration if the cap was able to hold the mixture under pressure the longer time. The conclusion was to seal the mixture with the better variant of the cap. Therefore, the plastic caps were used and there was a significant shift which can be seen on the last sequence of images. The first sign can be seen within the limit of 10 ms (See Fig. 12), but in this case can be seen magnesium igniter with better cap. In comparison with previously tested samples the response was faster. At the same time, other better visual exposure similar to the exposure of Sobbe igniters were seen.

Conclusion

The recording by high-speed camera was really important for the possibility of improvement of caps and for the comparison of visual exposure. The four dust substances, for which optimal concentration was known, were used to find out how the explosion parameters are influenced. The used substances include niacin, lycopodium, blue toner colour and black coal. Based on the knowledge of their optimal concentration, the explosion autoclave was used to verify if prepared pyrotechnical igniters influence the monitored parameters - the maximal explosion pressure and the rate of increase of the maximal explosion pressure.

The average measured values of individual dust mixtures and used types of pyrotechnical mixtures for the initiation are summarized in Tab. 1. For both monitored parameters, the noticeable difference in size can be seen when Sobbe igniters were used. The values of these initiation source are greater than those of prepared alternative pyrotechnical igniters.

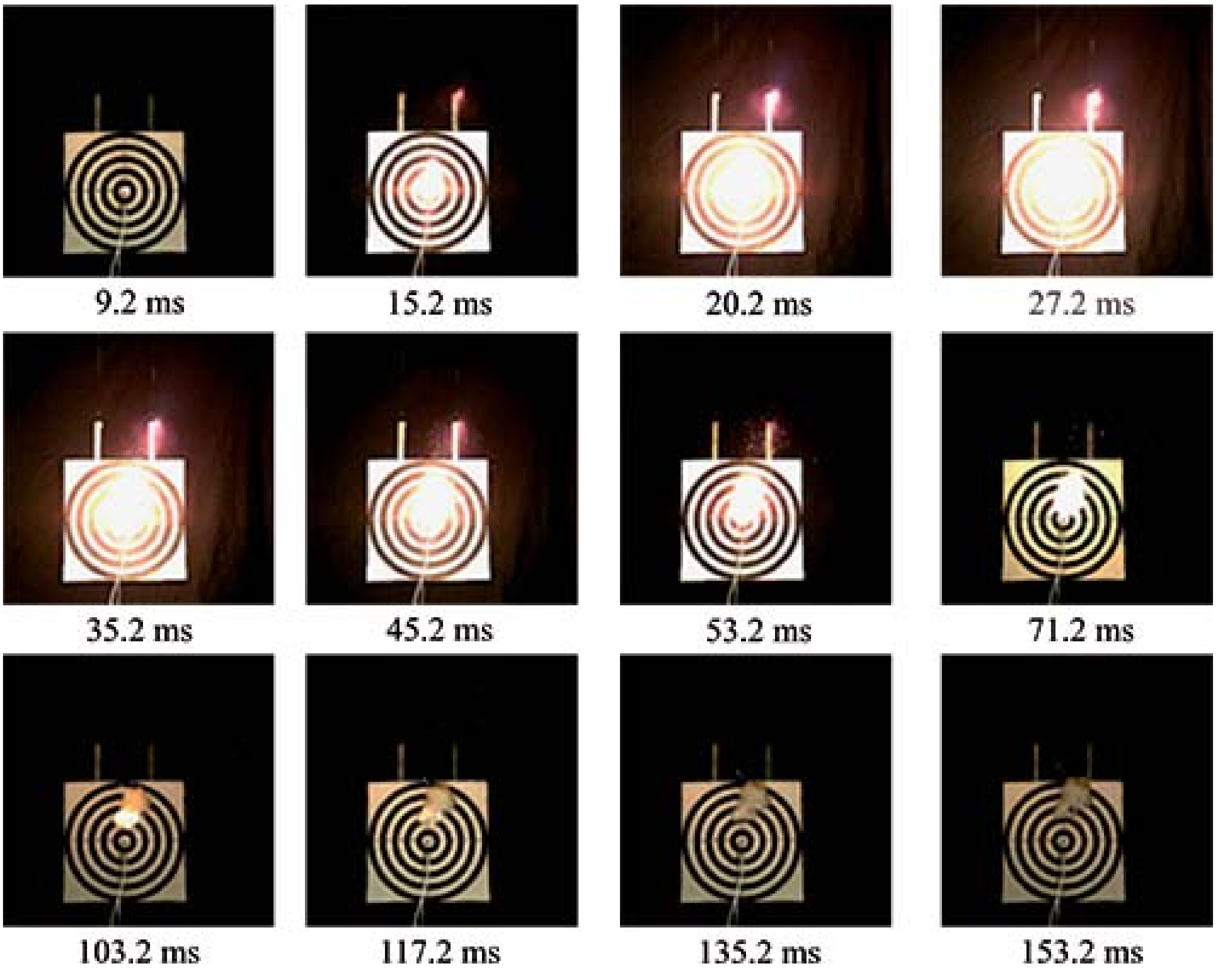

Fig. 12. Initiation of Magnesium igniter

The greatest influence is seen at the rate of increase of the maximal explosion pressure which is twice as big. If alternative sources are compared to each other there are no major variations.

Out of the performed experiments it is evident that alternative mixtures for the initiation of dust mixtures are useful. However, the necessary optimalization of the composition of mixtures and the manner of cap closing of the pyrotechnical igniter have to be carry out. The difference in the rate of the increase of the maximal explosion pressure is not insignificant. The results are different and the use of alternative pyrotechnical igniters may cause a misrepresentation of the real explosion properties.

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Tab. 1. Explosion parameters of selected dust-air mixtures

Type of igniter	Niacin		Lycopodium		Blue toner colour		Black coal	
	p_{max} [bar]	$(dp/dt)_{max}$ [bar.s^{-1}]	p_{max} [bar]	$(dp/dt)_{max}$ [bar.s^{-1}]	p_{max} [bar]	$(dp/dt)_{max}$ [bar.s^{-1}]	p_{max} [bar]	$(dp/dt)_{max}$ [bar.s^{-1}]
Sobbe - 10 kJ	8.03	974.6	7.20	982.0	7.60	973.6	7.63	442.66
Aluminium - 10 kJ	7.13	460.0	6.40	251.6	7.26	595.3	6.93	219.66
Magnesium - 10 kJ	7.30	482.0	6.83	313.3	7.13	562.6	7.13	225.66
Sobbe - 2 kJ	7.20	667.0	6.76	475.3	7.40	1033.3	7.20	424.33
Nitrocellulose - 2 kJ	7.23	398.6	6.70	305.6	7.23	603.3	6.86	212.33

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